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A documental approach to adventure game development

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Abstract

In this paper, we propose a documental approach to the development of graphical adventure videogames. This approach is oriented to the production and maintenance of adventure videogames using the game's storyboard as the key development element. The videogame storyboard is marked up with a suitable domain-specific descriptive markup language, from which the different art assets that are needed are referred to, and then the final executable videogame itself is automatically produced by processing the marked storyboard with a suitable processor for such a language. This document-oriented approach opens new authoring possibilities in videogame development and allows a rational collaboration between the different communities that participate in the development process: game writers, artists, and programmers. We have implemented the approach in the context of the <e-Game> project, by defining a suitable markup language for the storyboards (the <e-Game> language), and by building a suitable processor for this language (the <e-Game> engine).

Keywords: Videogames; Adventure games; Development process; Document-oriented approach; Storyboard markup language; Game engine

1. Introduction

The development of videogames, which started out as small individual projects initiated by groups of friends, has evolved rapidly in the last few years into a massive entertainment industry. Nowadays, videogames are huge software projects developed by heterogeneous teams, usually grouping more than one hundred people. Therefore, it is no longer possible to have a single programmer coding a game, and advanced software engineering techniques have become a necessity [34].

This paper addresses the relationships between *game writers*, *artists* and *programmers* in the development of *graphical adventure videogames* [15]. The skills of the different participants in the development of this kind of game are usually orthogonal, but their collaborative work is essential for the successful development of the final product. The main role of game writers is to create the *game storyboard*, where the story, development and all the different

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elements of the game are described. Artists in turn are engaged in producing the artworks that are integrated in the final game (e.g. graphical designs, musical compositions, etc.). Finally, programmers are in charge of implementing and customizing the software infrastructure of the game.

We propose a *documental approach* to rule the collaboration between the aforementioned communities. In this approach, the final program implementing the videogame is not the centre of the development process because the focus is on producing and maintaining the game storyboard. For this purpose, the structure of this document is characterized and formalized in terms of an easy-to-use and easy-to-understand descriptive markup language that can be used by game writers to make the structure of their storyboards explicit. This approach follows the concepts described in [6,11,12], where the writer of a document of a given type (a book, a technical manual, etc.) can use a descriptive markup language tailored to such a document type. In the context of this project, additional markup is added to refer the assets provided by the artists, and executable games can be automatically generated from the marked up storyboards by using a suitable processor for the descriptive markup language. An entire family of videogames (in this case, classic graphical adventure games) shares this processor. The processor is provided and maintained by the programmers. In this approach, game writers, who are the true experts in the conception of adventure videogames, rule the writing and development process.

We have implemented the documental approach in the <e-Game> project. This project proposes a development process model centred on the creation of a complete script or storyboard that is then marked with a domain-specific XML-based markup language (the <e-Game> *language*). The resulting marked document, along with the art assets to be integrated in the final game, can be interpreted by a highly modular and extensible processor (the <e-Game> *engine*) in order to automatically produce the executable videogame. Since writers are the main stakeholders in the process, <e-Game> focuses on facilitating their task as much as possible. A high level of technological skill should not be a requirement, which makes it necessary to design the process in such a way that authors will be able to develop all their potential without having to struggle with programming concepts. It should also be noticed that the main contribution and innovation of the work presented in this paper is not the use of specific standards or technologies (e.g. XML), but the use of the basic principles behind descriptive markup in the production and maintenance of graphical adventure videogames. These principles promote the separation between document structure and processing, and lead to a rational separation of roles in the development process.

The structure of this paper is as follows. In Section 2, we briefly survey some related work in the field of domain-specific languages and tools for the development of videogames. In Section 3, we describe the document-oriented process model proposed by <e-Game>. The <e-Game> language is presented in Section 4. The <e-Game> engine is described in Section 5. Section 6 presents a qualitative evaluation of <e-Game>'s usability. Finally, Section 7 provides some conclusions and lines of future work.

2. Domain-specific languages and tools for creating videogames

The notion of allowing authors (as opposed to programmers) to create videogames is not new. Videogames capture the imagination of all ages and genres [9] and the concept of allowing authors to develop their own videogames without the distraction of complex low-level programming is quite popular. Many initiatives allow for this kind of rapid development, all with different approaches and varied levels of sophistication. These initiatives can be broadly categorized into three different approaches: *authoring environments* for non-programmers, *scripting solutions*, and *special-purpose programming languages*. The following subsections briefly outline each one of these alternatives.

2.1. Special-purpose programming languages

There are programming languages specifically designed for videogame development that require authors to have good programming skills. Perhaps the most popular option nowadays is the *DarkBasic*[1] project [13]. Dark Basic and its spin-offs (DarkBasic Pro or the DarkMatter SDK with C++ support) are probably the main references when speaking about specific videogame programming. A previous initiative in the field, the DIV Games Studio,[2] had a

[1] http://www.thegamecreators.com/.
[2] http://www.divsite.net/.

reasonable success in the late 90s, although it was never properly supported by its publishers. However, several open-source initiatives emerged from within the DIV community and projects like *Fenix*,[3] *eDIV*[4] or *cDIV*[5] are still valid alternatives to DarkBasic.

A common characteristic of all these languages is that they include functionalities specially suited for videogame development. These functionalities usually act as simplified high-level wrappings of complex low-level constructions typically found in videogames (graphics management, game synchronization, sound management, collision detection, etc.). However, they are full-featured programming languages and, therefore, their use is too complex for the average user without an extensive programming background.

2.2. Scripting languages

Many modern videogames separate low-level logic from data and high-level definitions of the behaviour of the game (AI management, game design, etc.). The core of such games is an *engine* that may have been specifically built, reused from previous development, or provided by a third party. This engine is written by expert programmers, but it is not a game in itself. The game is actually a set of scripts that are interpreted and executed by the engine [31].

The advantage of scripting approaches is that these languages are usually simpler than full-featured programming languages, which facilitates game programming and maintenance. There are many scripting languages with different approaches and levels of complexity. Sometimes scripting languages are designed for a specific game engine, although general purpose languages such as LUA [14] are used in many developments.

Some commercial games disclose their scripting languages to promote the appearance of *modding communities*, formed by non-affiliated players that create customizations and modifications of the game. Sometimes this approach is so flexible that communities have developed completely new games.[6]

This approach has a clear advantage: If the scripting language is targeted to a specific game (or family of games), it is possible to simplify the language by abstracting different elements of the game. This is useful in graphical adventure games that include many widely accepted commonalities. Thus, there are several engines and scripting languages specifically tailored to suit the needs of the genre. Some common examples are initiatives like the *MAD Adventure Game Engine*[7] (which uses LUA as a scripting language), *SLUDGE*[8] (Scripting Language for Unhindered Development of a Gaming Environment) or the *WinterMute Engine*[9] (featuring a very powerful Object-Oriented scripting language). A pioneer of this approach was the *SCUMM* system [33], employed in most commercial LucasArts [43] games, but not available for the general public.

The genre of graphical adventure games is very synergetic with the Interactive Fiction (IF) community (text-based adventures, in which the computer is used as a medium for the delivery of richly interactive stories). The IF scene is dominated by scripting initiatives like *TADS*[10] (originally developed in 1987, it nowadays uses an object-oriented language with Pascal-like syntax), *INFORM*[11] (developed in 1993, it has a customizable parser, which by default supports a C-like language) and *HUGO*[12] (developed in 1995 with a syntax reminiscent of Basic). Although all these initiatives were developed with IF and text-based adventures in mind, nowadays they all also support graphics and sounds to different extents, thus making them suitable for the development of graphical adventure games.

Even though scripting languages are usually easier to learn and to use than general-purpose programming languages, they still demand that authors have good programming skills. Therefore, they are not accessible for average authors but only for those with certain skills in computer science or highly motivated enthusiasts.

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[3] http://fenix.divsite.net.

[4] http://ediv.divsite.net.

[5] http://cdiv.sourceforge.net/.

[6] The engine of the science fiction game Half-Life is the base for the more realism-oriented Counter Strike, arguably the most popular multi-player First-Person-Shooter.

[7] http://mad-project.sourceforge.net/.

[8] http://www.hungrysoftware.com/tools/sludge/.

[9] http://www.dead-code.org/index2.php/en.

[10] http://www.tads.org/.

[11] http://www.inform-fiction.org/.

[12] http://www.generalcoffee.com/hugo.html.

2.3. Authoring approaches

On the *no-programming* side of the spectrum, there are several authoring proposals that allow authors to create videogames without resorting to programming. These initiatives usually trade expressive power for simplicity, although some include an extension mechanism with sophisticated programmatic resources for more advanced users.

One of the most popular initiatives is the *Game Maker*,[13] which has been used as a rapid development tool in a number of academic research projects [1,29,32]. There are also similar commercial projects like *The FPS Creator* (for quick creation of typical First-Person-Shooters with just a few mouse clicks) or the more sophisticated *The 3D Game Maker* (also GUI-driven, although much more powerful), both produced by the same company that distributes DarkBasic.[14] Finally, the academic-oriented *ToonTalk* [17] takes a radical approach, where the development environment is a game itself, designed to be usable by children but without compromising expressive power. It must be noted that ToonTalk can be used for the development of any kind of program, and not only videogames.

Regarding the narrower domain of graphical adventure games, there are also several initiatives that promote an authoring approach. For example, the *Adventure Game Studio*[15] (a drag and drop tool, although it does support some scripting optionally), the *Adventure Maker* project[16] (which can target the games produced to the PlayStation Portable console), or the *3D Adventure Studio*[17] (which provides a very simple GUI for the creation of 3D adventure games, but is still at a very early stage of development).

In the IF field, there are also examples of the authoring approach that try to eliminate programming to allow authors without a technical background to participate. Since most authors in the scene define themselves as closer to writers of novels than to programmers, it is especially important to have tools that do not require any programming background. In this regard, *ADRIFT*[18] is probably the most extended tool, allowing the author to create the adventures using a number of windows and forms, and with an extended support for graphics and sounds that, again, blurs the barriers between Interactive-Fiction and graphical adventures. A more classical approach like *ALAN*[19] provides a language similar to written English and is considered as a modern alternative to the classic *AGT*.[20]

While the author-centred conception maintained by these approaches is in accordance with our documental approach, they are usually oriented to the description of the different features of the videogame as an executable artefact. In addition, all these initiatives assume that the process is focused on the tool that you use. There is no well-defined development process, and it is common to start writing the game with the tool itself (although having a full script previously written would be desirable). In this paper, we propose a different general approach, focused on producing and maintaining the document with the storyboard describing the game. The proposed development process permits a rational collaboration between the different participants in this process.

3. Document-oriented development of adventure videogames: The <e-Game> project

In the last ten years, our research group at the Complutense University of Madrid has been applying a *document-oriented* approach to the development of content-intensive applications (e.g. e-learning systems, museum object repositories, knowledge based systems, etc.) [10,35,36,40]. These applications share the common feature of integrating large amounts of highly structured content that is usually authored by domain experts (as collections of well-structured documents). With these requirements, the approach focuses on the production and maintenance of the documents with their content, and with the other aspects of the application (e.g. some features of the user interface) instead of the application itself. The structure of these documents is then made explicit by marking them up with suitable domain-specific descriptive markup languages, which are specific for each particular application domain.

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13 http://www.gamemaker.nl.
14 http://www.thegamecreators.com/.
15 http://www.adventuregamestudio.co.uk/.
16 http://www.adventuremaker.com/.
17 http://3das.noeska.com/.
18 http://www.adrift.org.uk/.
19 http://www.alanif.se/.
20 http://www.markwelch.com/agt.htm.

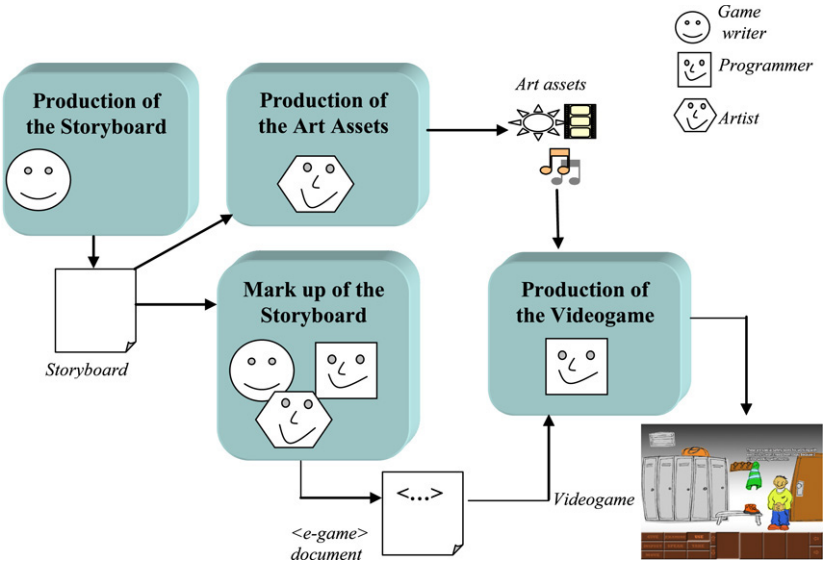


Fig. 1. The <e-Game> development process.

Finally, applications are automatically produced by processing the documents with suitable processors. Therefore, the approach greatly improves the collaboration between domain experts, who are mainly responsible for producing and maintaining the documents, and developers, who are responsible for formalizing the markup languages and building their processors.

The main goal of the <e-Game> project is to apply the documental approach to the development of graphical adventure videogames [21,22,24,25]. The idea is to allow game writers without a strong technical background to produce and maintain an entire game as a document using a language that is easy-to-understand, which is then fed to a compiler/interpreter that produces a fully functional game. In addition, the approach also defines a model of collaboration with other stakeholders: artists and developers. The resulting process model is outlined in Fig. 1, where the development activities, the participants in these activities, and the main products produced during the <e-Game> development of a videogame are outlined. In support of this process model, two different components are introduced: the <e-Game> language, which is used by writers to mark their storyboards up, and the <e-Game> engine, which is used for executing the games from the storyboards describing them, once marked up with the <e-Game> language. While these two components are detailed in the next sections, here we will give a high-level description of the development process model introduced by <e-Game>.

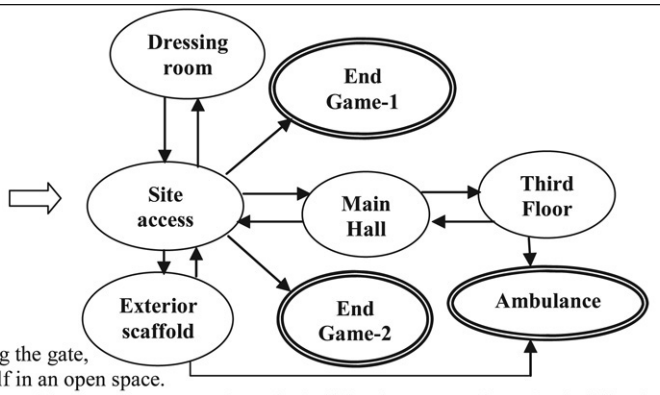
In order to illustrate the development process model, as well as other aspects of the <e-Game> project, a very simple educational graphical adventure game has been taken as a common case study. This game is designed to be used as a support tool in a course on workplace safety regulations. The game describes the story of *José*, a young unemployed worker who gets a job at a construction site. During his first trial week, the worker must perform the different tasks ordered by the *foreman*, paying special attention to workplace safety regulations. Whenever the player omits a safety regulation, he either is injured or is rebuked by the foreman.

The following subsections detail the different aspects of the process model from the perspective of its activities.

3.1. Production of the storyboard

The development process model proposed by <e-Game> starts with the independent elaboration of a storyboard of the adventure game, written in a plain natural language (e.g. English). The game writer carries out this activity. <e-Game> imposes some guidelines restricting the style of the resulting document in order to facilitate its subsequent markup. Summarizing:

- The writer should begin by documenting the different *scenes* and *cutscenes* that form the adventure game. *Scenes* are the basic modelling units in <e-Game>, and correspond to the different locations that can be visited when



Site access
Description
Just after crossing the gate, José finds himself in an open space.
There is a small pre-fabricated barn apart from the building in construction. The building has four floors and one of its walls is surrounded by a scaffold.
Objects:
Crowbar: There is a crowbar lying on the floor.
Exits:
Barn door: The barn has a door that leads to the "Dressing room"
Building gate: Leads to the "Main Hall".
Exterior gate: Only available after completing all the tasks indicated by the foreman. It leads to either ending cutscene (End Game 1 or End Game 2) according to whether the user has returned all the tools to the toolbox.
Characters:
Foreman: the foreman is standing in front of the building.
Story: (….)

Fig. 2. An excerpt of the sample storyboard displaying the map and the description of a scene. End game cutscenes are identified by a double circle.

Toolbox
Description: It is a standard toolbox
Detailed Description: Safety regulations demand that work tools are always stored properly. I should put here any tools I find around.
Actions: The toolbox can not be grabbed. Different tools may be used with the toolbox and be stored into it.
(…)

Fig. 3. Storyboard definitions of some objects.

playing it. Typical examples might be a dressing room, a construction site, or a street. *Cutscenes*, in turn, can be considered as special kinds of scenes that can be used to include special events in the game's flow (e.g. to play a video with some sort of explanation about the game). The writer should also indicate the contents of the scenes' (*objects* and *characters*), and indicate the connections between these scenes. The storyboard from our sample also includes a conceptual map of the scenes that clarifies the connections, as depicted in Fig. 2. It must be noted that the different objects and characters that populate the scenes are not defined directly. Instead, they will be detailed later. This has the advantage of being more modular and naturally leads to a systematic writing methodology.

- After defining all the scenes and cutscenes, the author is advised to give details about the objects populating the scenes. This definition should resemble that given in Fig. 3.
- Following the <e-Game> guidelines, the next step is to describe the player and the rest of the characters as in Fig. 4. Again, rather than writing out the entire contents of the different conversations, only a brief explanation is given instead. The actual content of the conversations will be detailed later.
- The last step is to describe the conversations supported by the characters. Conversations are perhaps the most delicate element in a graphical adventure. Most of the game's content and clues are obtained by interacting with characters (although the use of visual clues is also common). A long, enticing conversation with varied interaction options and different possible outcomes is one of the aspects that requires more

José
José is an eager young man trying to make some money. He is not an unexperienced worker, although he is not familiar with the safety regulations in the Spanish workplace.
Description: Hey! It's me!
Detailed Description: I'm not as fit as I used to be. I hope this job will help me to lose some weight.

The foreman
The foreman is well into his forties. He always smiles and treats his employees fairly, although he usually gets angry at the sight of any breach of safety regulations due to a past bad experience that he never talks about.
Description: A friendly man with occasional bursts of anger.
Detailed Description: He is the foreman in this construction site. I think I'd better not make him angry, for my work depends on his reports.
Conversations:

- "Greeting": The first time he speaks, he greets José and welcomes him. He advises José on clothing regulations and suggests he go to the dressing room.
- "Undressed": If after the first conversation José speaks with the foreman, he is directed to the dressing room.
- "First task": The foreman asks José to go to the third floor and collect some sacks of sand that must be brought down to the hall.
- "Complete first task": If José is in the middle of the first task, the foreman insists that he must complete the action. (…)

Fig. 4. Storyboard definitions of the player (José) and some characters (The Foreman).

```
F: Well José, have you measured the scaffold?
  ->J: No sir, not yet
       F: And what are you waiting for?
       J: At once, sir
  ->J: Yes sir, it's ready
       F: And...
          -> J: It's rather high, sir
               F: That is not a reliable measurement!
               F: I need precise data (go-back)
          ->J: It is 2.5 meters high, sir
               F: Hmmmm....
               F: That is over the 2 meter limit
               F: It must have handrails then and the plank must be wider than 60 centimeters
               F: Does it comply to those specifications?
                 ->J: Yes, it does
                      F: Ah, that's perfect
                      F: In that case, I need you to climb to the top of the scaffold
                      F: and help David with the window frames
                      J: Yes, sir (end of conversation)
                 ->J: No, it doesn't
                      F: I can't believe they installed a bad scaffold!
                      F: Please, check it out again or I will have to call them
                      F: and have a new scaffold installed
                      F: That would delay the entire schedule! (end of conversation)
```

Fig. 5. Conversation between José and the foreman.

dedication from the author. In addition, one of the main checkpoints for the quality of such an adventure is the quality of its dialogues. <e-Game> works with the model of multiple-choice dialog structures organized as a tree, with the possible answers as nodes that open to new sub-conversations. We recommend using a format to describe the conversations that reflects the notion of a tree like the one suggested in Fig. 5.

After completing the conversations, the writer has a document that describes the complete game, defining scenes, navigation, objects, characters, and all the possible interactions. This document is the most valuable asset produced during the development process, since it contains the essence and is the key to the success of the final videogame.

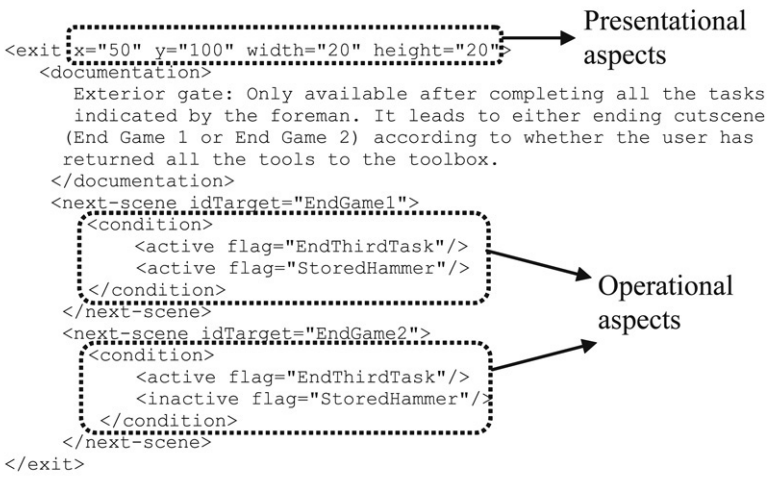


Fig. 6. Example of markup in <e-Game>. The markup makes the rhetorical structure of the storyboard explicit, and also includes other operational and presentational aspects.

Therefore, the documental approach develops the idea that the entire development process be focused on this document. In the end, the videogame itself will be automatically produced by processing this document, although this requires the author to define its structure explicitly.

3.2. Mark up of the storyboard

The goal of this activity is to mark up the storyboard using a suitable domain-specific markup language that indicates its structure and the semantics of each portion of the document. In addition, the language proposed in <e-Game> also includes markup to describe the presentational and operational aspects needed for the execution of the actual game. The <e-Game> language itself will be detailed in Section 4.

The main workload of this activity also falls to the game writers. Nevertheless, the markup must also formalize aspects that are not so straightforward for the writers and may hence require the assistance of the other stakeholders.

First, as will be detailed in Section 4, the language requires some occasional deep thinking while formalizing abstract ideas about the state of the game. In the example shown in Fig. 6, the statement "*Only available after completing all the tasks indicated by the foreman*" found in the description of the exit *Exterior Gate* in the definition of *Site Access* is establishing a condition for traversing the exit that must be adequately formalized. For this purpose, the programmers may also be involved in the mark up process, in order to advise writers about the description of these *operational aspects* of the <e-Game> document.

As shown in Fig. 6, there are some presentational characteristics that must also be made explicit in the markup. In the example, it is necessary to indicate the coordinates and dimensions of the rectangle that delimits the exit (i.e. the zone that triggers the change of scene when clicked with the mouse). This process requires access to the art assets, and therefore, the collaboration of the artists.

Nevertheless, our experience is that these situations can be tackled without excessive effort in typical adventure games. The process is not overly complex, and most writers are comfortable enough so as to need barely any assistance, as detailed in Section 6.

3.3. Production of the art assets

In this activity, the artists, following the descriptions of the storyboard, produce the different artwork that will finally be integrated into the game. The resulting files can be referred from the markup added to the storyboard, therefore yielding a complete description of the final videogame.

In Fig. 7, some art assets for the proposed case study are shown. It is important to note that these assets can be changed by others if required, while most of the effort applied in the production of the storyboard and the markup process is preserved (presentational markup as object coordinates may need some adjustments). This possibility is

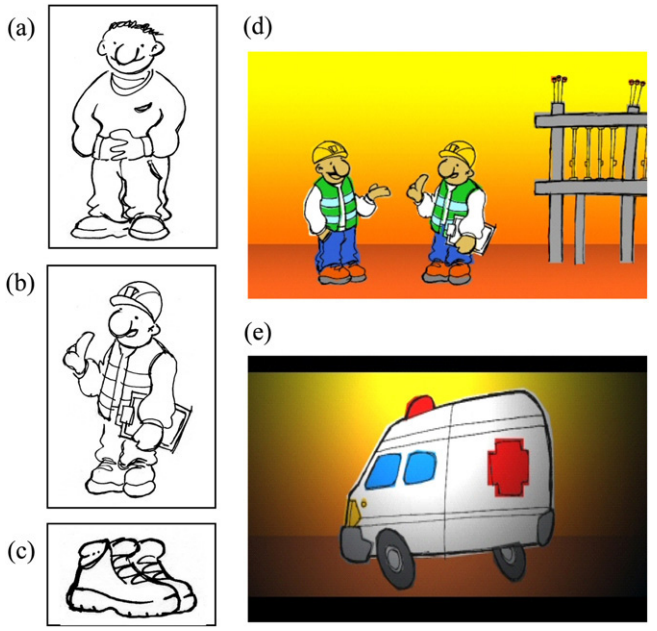


Fig. 7. Some simple artworks from the case study: (a) draft of the player's avatar, (b) the Foreman, (c) sprite for an object (boots), (d) a composed scene (Site Access), (e) a frame of a cutscene (ambulance).

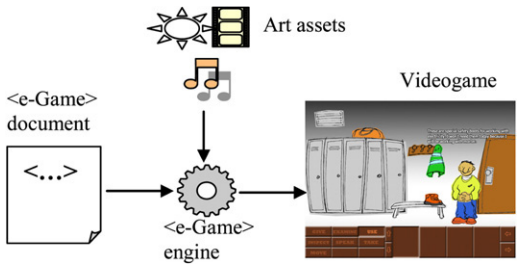


Fig. 8. The videogame is automatically generated by processing the <e-Game> document and the art assets with the <e-Game> engine.

a direct consequence of the documental approach and the descriptive markup spirit, which promotes an explicit separation between content, structure, and the subsequent processing of the marked documents.

3.4. Production of the videogame

Once the <e-Game> document with the marked storyboard and the art assets are available, the videogame can be produced by processing all this material with the <e-Game> engine (Fig. 8).

The <e-Game> engine, which will be described in Section 5, is highly modular and configurable. This allows programmers to extend it with the appropriate components in order to accommodate the particular needs of a videogame. For instance, the introduction of more sophisticated art assets and presentation requirements in a game can be readily accommodated in a systematic way by customizing the <e-Game> engine with new presentation capabilities. In addition, the newly added components can be reused both in the production of future versions of the game and of other similar games.

4. The <e-Game> language

The <e-Game> language allows game writers to describe a graphical adventure game as a document containing the game's storyboard, and to mark this document up using easy-to-use and easy-to-understand descriptive markup. Therefore, the game writer does not specify how the characters move or how the lighting works, but what the actual content of the game is (i.e. scenarios, items, conversations, etc.).

```
<!ELEMENT eGame (title?, story?, (scene | cutscene)+, object*,
                 player, character*, conversation*)>
<!ELEMENT title (#PCDATA)>
<!ELEMENT story ANY>
```

Fig. 9. <e-Game> DTD fragment defining the top-level structure for an <e-Game> document.

The <e-Game> language is an XML *application* (i.e. a markup language defined using XML). XML is the *de facto* standard markup metalanguage recommended by the World Wide Web Consortium [3]. Human readability for the defined markup languages is one of the key XML design features, which makes XML especially well suited for our needs. In addition, XML languages can also readily include mechanisms for the identification and reference of document elements, which will be very useful in the context of <e-Game> for modelling scenes, characters and conversations separately, and then linking them by using references. Finally, XML also allows the description of the markup languages using declarative grammatical formalisms [20,28] such as DTDs (*Document Type Definitions*) [42] and XML Schemas [8]. It is important to note that XML is used here with an emphasis on its original use as a document markup metalanguage, instead of its use as a storage format definition language.

Although we have formulated <e-Game> in terms of an XML Schema in order to facilitate language extensibility and evolution, for the sake of simplicity in this paper we will describe the structure of the language using an XML DTD, since this formalism is less verbose and more easily understood by most people.

In the following subsections, the different aspects of the language are detailed from a technical point of view. The examples relate to the aforementioned educational game about workplace safety regulations.

4.1. Top-level <e-Game> document

As described in the previous section, an <e-Game> document is structured as a sequence of *scenes* and *cutscenes*, *objects*, the description of the *player*, *characters* and *conversations*, which are marked up as an `eGame` element, as indicated in Fig. 9.

As indicated in Fig. 9, an <e-Game> document also includes the game's title (it must be marked up as a `title` element), and a summary of the game's story (marked up as a `story` element). This kind of human-readable documentation will usually be ignored by the engine described in Section 5, although it will be very valuable for designers and developers during the production and maintenance stages, since it is an integral part of the game's storyboard.

4.2. Flags and conditions

An unstructured plain game, where every door is always open, every character always says the same things and every exit leads to the same place is too limiting. An absolute lack of order could lead to incoherence and could make it difficult to perceive any progress in the game. A graphical adventure requires a sense of narrative coherence in the succession of events. We can achieve this by introducing a notion of *state*. Every action performed in the game should be able to affect future actions. Some objects may be hidden until something happens (e.g. the object appears only if the player has performed a given action), some exits may be locked (e.g. you can't use the elevator unless you have been instructed to do so and have received the key), or a character may offer a different conversation (e.g. the foreman does not always give the same commands). The <e-Game> language allows a declarative representation of the game's state which is mainly based on boolean propositional variables called *flags*. These variables can be used to describe the conditions that the player must have previously achieved in order to be allowed to carry out an action in a game, such as to see an object or activate an exit. When a flag holds, it is said to be *active*. Otherwise, it is said to be *inactive*.

This can be conceptually modelled by allowing each interaction (with an object or character) to activate a condition. Then, we can add preconditions to anything we want in the form of a list of conditions that indicate which actions must have been performed. The state in any given point of the game is determined by a set of actions that have already been performed.

In Fig. 10(a) the markup used to describe conditions is formalized. Notice that conditions are expressed as *conjunctive normal forms* on the flags. Indeed, atomic conditions are introduced either with an `active` element

(a)
```
<!ELEMENT condition (%basic-condition; | either)+>
<!ELEMENT active EMPTY>
<!ATTLIST active flag NMTOKEN #REQUIRED>
<!ELEMENT inactive EMPTY>
<!ATTLIST inactive flag NMTOKEN #REQUIRED>
<!ELEMENT either (%basic-condition;)+>
<!ENTITY % basic-condition "(active|inactive)">
```

(b)
```
<condition>
   <active flag="FirstTaskInitiated"/>
   <either>
       <inactive flag="UsedSandSack1Container"/>
       <inactive flag="UsedSandSack2Container"/>
   </either>
</condition>
```

Fig. 10. (a) DTD fragment for conditions; (b) an example of condition.

(requiring a flag to be active) or with an `inactive` one (requiring it to be inactive). The flags themselves are indicated using `flag` attributes. Clauses (disjunctions of atoms) are expressed using `either` elements. In turn, conjunctions are marked up as `condition` elements. As stated in Section 6, we have realized that, in the context of graphical adventure games, the use of conjunctive normal forms is more natural for writers than the use of disjunctive ones (i.e. the presence of several groups of conditions interpreted as different alternatives).

Fig. 10(b) shows a meaningful condition in our case study. It is important to note that in spite of the formal grounding of the condition system, the resulting markup is not far from how an author would write conditions in a storyboard: "The worker can only use the lift if he has been instructed to go to the third floor (FirstTaskInitiated) but hasn't yet collected both sacks of sand (one of the sacks cannot have been dumped in the container yet)".

4.3. Effects

<e-Game> also allows a declarative representation of the effects caused by the different actions performed during the game. These effects are described using the markup formalized in Fig. 11(a). In Fig. 11(b), the use of this markup is exemplified in the case study. Lists of effects are marked up as `effects` elements. Individual effects can be in turn of the following types:

- Activation of a flag. The most transcendent effect of an action is the activation of a flag (and thus modifying the state of the game). This is noted as an `activate` element and the activated condition is indicated with a `flag` attribute. Notice that in <e-Game>, it is not possible to *deactivate* flags, since it includes a monotonic notion of logical truth: once a proposition becomes true, it will stay true forever. Intuitively, a flag represents an achievement, which cannot be "unachieved".
- Consumption of an object. Like most of the usual adventure games, games in <e-Game> maintain an *inventory* of objects, which can be used in different ways. Some of these uses (e.g. combining the object with another one in a specific way) can cause the consumption of the used objects. This change is expressed using a `consume-object` element. The object actually consumed will be determined by the context of the effect.
- Lines spoken by the characters. Some actions can cause the characters populating a scene to say something. Lines said by the player's avatar are marked up as `speak-player` elements, while phrases said by characters are marked up as `speak-char` elements. In this last case, the character that speaks the line is determined by the context.
- Triggering a cutscene. Some actions can cause the visualization of a cutscene illustrating their consequences. This effect is described using a `trigger-cutscene` element. The cutscene is referred to with an `idTarget` attribute. If there is a sequence of effects, this type of effect must be the last one to appear, since when entering a cutscene, the action will continue from that cutscene.

4.4. Resources

The presentation of the different elements (scenes, cutscenes, objects, player(s), and characters) involved in a game requires the location of external assets provided by the artists (e.g. background bitmap, environmental music, hardness maps, etc.). Therefore, for each element to be presented, it is possible to associate a set of *resources* containing

(a)
```
<!ELEMENT effects ((activate|consume-object|speak-player|
                    speak-char)*,trigger-cutscene?)>
<!ELEMENT activate EMPTY>
<!ATTLIST activate flag NMTOKEN #REQUIRED>
<!ELEMENT consume-object EMPTY>
<!ELEMENT speak-player (#PCDATA)>
<!ELEMENT speak-char (#PCDATA)>
<!ELEMENT trigger-cutscene EMPTY>
<!ATTLIST trigger-cutscene idTarget IDREF #REQUIRED>
```
-0-

(b)
```
<effects>
     <speak-player>Aaaahhhhh!!!</speak-player>
     <activate flag="PlayerDamaged"/>
     <trigger-cutscene idTarget="Ambulance"/>
</effects>
```

Fig. 11. (a) Markup for effects; (b) example of effects.

(a)
```
<!ELEMENT resources (condition?, asset+)>
<!ATTLIST resources id ID #IMPLIED>
<!ELEMENT asset EMPTY>
<!ATTLIST asset type CDATA #REQUIRED uri CDATA #REQUIRED>
```
-0-

(b)
```
<resources>
    <asset type="image/jpeg" uri="images/background1.jpg"/>
    <asset type="audio/mpeg" uri="sounds/working1.mp3"/>
</resources>
```

Fig. 12. (a) Markup for the resources; (b) sample resources for a scene of the game.

(a)
```
<!ELEMENT scene (documentation?, resources*, exits, objects?,
                 characters?)>
<!ATTLIST scene id ID #REQUIRED start (yes|no) "no">
<!ELEMENT documentation ANY>
<!ELEMENT exits (exit+)>
<!ELEMENT objects (object-ref+)>
<!ELEMENT characters (character-ref+)>
```
-0-

(b)
```
<scene id="SiteAccess">
 <documentation>
Just after crossing the gate, José finds himself in an open space.
There is a small pre-fabricated barn apart from the building in
construction. ...
...
 </documentation>
 <resources>  ...   </resources>
 <exits>      ...   </exits>
 <objects>    ...   </objects>
 <characters> ...   </characters>
</scene>
```

Fig. 13. (a) Markup for the scenes; (b) simplified example of using the markup for describing a scene.

references to all the artworks required. The markup used in <e-Game> to refer to these assets is depicted in Fig. 12(a). Each asset is referred to using an `asset` element. The `type` attribute allows the identification of the asset's type (e.g. a *jpg* image, an *mp3* file, etc.), while `uri` is used to locate the actual asset. Also, notice that a set of resources can be made conditional on an appropriate condition. This allows authors to tailor the presentation of the elements to different circumstances (e.g. a character that changes her clothes or a chest that appears open or closed depending on the state of the game).

In Fig. 12(b), we illustrate the use of resources with a (very simplified) example where a background image and an ambient sound for a scene are referred to.

4.5. Scenes

Scenes in <e-Game> are marked up with `scene` elements, using the structure formalized in Fig. 13(a). According to this definition, each scene can contain the fragment of the storyboard that describes its structure, context and other

```
<!ENTITY % position   "x NMTOKEN #REQUIRED y NMTOKEN #REQUIRED">
<!ENTITY % rectangle "%position; width NMTOKEN #REQUIRED
                                 height NMTOKEN #REQUIRED">
<!ELEMENT exit (documentation?, next-scene+)>
<!ATTLIST exit %rectangle;>
<!ELEMENT next-scene (condition?, effects?)>
<!ATTLIST next-scene idTarget IDREF #REQUIRED
                     xTarget NMTOKEN #IMPLIED
                     yTarget NMTOKEN #IMPLIED>
```

Fig. 14. Markup for the exits.

(a)

```
<!ELEMENT object-ref (documentation?,condition?)>
<!ATTLIST object-ref idTarget IDREF #REQUIRED %position;>

<!ELEMENT character-ref (documentation?,condition?)>
<!ATTLIST character-ref idTarget IDREF #REQUIRED %position;>
```

(b)

```
<object-ref idTarget="Hole" x="45" y="50">
 <documentation>Hole:There is a big hole in the middle of the room.</documentation>
  <condition>
     <inactive flag="UsedFencesHole"/>
  </condition>
</object-ref>
...
<character-ref idTarget="Foreman" x="45" y="200">
  <documentation>The foreman is standing in front of the building.</documentation>
</character-ref>
```

Fig. 15. (a) Markup for the references to the objects and the characters in a scene; (b) example of use of the markup described in (a).

aspects concerning it (`documentation` element). The scene also contains the list of alternative resources needed for its visualization, the sequence of exits leading to other scenes or cutscenes (`exits` element), the objects (`objects` element), and the characters (`characters` element) that may appear in the scene. Notice that each element of type `scene` has associated with it an `id` attribute that identifies the element within the document. This feature, which is also shared by the other top-level elements, allows other elements to refer to it. In addition, it is possible to indicate that the scene is the starting point of the game by using the attribute `start`. These markup conventions are exemplified in Fig. 13(b), where the (simplified) top-level markup for a scene in the case-study is depicted.

In Fig. 14, the markup for the description of each exit is formalized. Each exit is marked up as an element of type `exit`. The exit is located in the scene with a bounding rectangle defined by the x and y coordinates in its upper-left corner, its height and its width (this information is encoded into the `exit` elements with attributes). In <e-Game>, it is possible to make the place where an exit leads conditional according to a condition formulated in the game's state. Therefore, and as indicated in Fig. 14, an `exit` element also contains a sequence of possible follow up scenes, each one marked up as a `next-scene` element. These elements can contain the conditions that must hold, and the effects achieved by traversing the exits under such conditions (in this context, such effects only contemplate the activation of flags). In turn, the target of the exit, which must be a scene or a cutscene, is referred to using `idTarget` attributes, and for scenes, the starting position for the player's avatar in the target scenes is referred with `xTarget` and `yTarget` attributes. The use of this markup is illustrated in Fig. 6 with an exit leading to different scenes depending on the holding condition.

Finally, the markup for the objects and the characters that can appear in a scene are characterized in Fig. 15(a). Again, it is important to take into account that such objects and characters are not described at this point. Instead, they are described as top-level elements in the <e-Game> document, and they are referred to in the scenes using `object-ref` and `character-ref` elements. The references are indicated using `idTarget` attributes.

In addition, it is important to note that the visibility of an object or character in a scene can depend on a condition of the game's state (element `condition`), as stated in Fig. 15(a). Indeed, objects and characters will be visible *only* when their associated conditions hold. Finally, the position of objects and characters in the scene are given using `x`, `y` attributes, and their role in the scene can be documented using a `documentation` element. The use of this markup is exemplified in Fig. 15(b).

(a)
```
<!ELEMENT cutscene (documentation?,resources*,next-scene*)>
<!ATTLIST cutscene id ID #REQUIRED start (yes|no) "no">
```

-0-

(b)
```
<cutscene id="LiftUp">
  <documentation>The lift is moving up</documentation>
  <resources>
      <asset type="video/mpeg" uri="video/liftup.mpg"/>
  </resources>
  <next-scene idTarget="ThirdFloor"/>
</cutscene>
```

Fig. 16. (a) Markup for the cutscenes; (b) an example of cutscene.

(a)
```
<!ELEMENT object (documentation?,instance*,
                  resources*,description,actions?)>
<!ATTLIST object id ID #IMPLIED>
<!ELEMENT instance EMPTY>
<!ATTLIST instance id ID #REQUIRED>
<!ELEMENT description (name,brief,detailed)>
<!ELEMENT name (#PCDATA)>
<!ELEMENT brief  (#PCDATA)>
<!ELEMENT detailed (#PCDATA)>
```

-0-

(b)
```
<object id="Toolbox">
 <documentation>...</documentation>
 <resources>...</resources>
 <description>
   <name>Toolbox</name>
   <brief>It is a standard toolbox.</brief>
   <detailed>Safety regulations demand that work tools are always stored
     properly. I should put here any tools I find around.</detailed>
</description>
    ...
</object>
```

-0-

(c)
```
<object>
  <documentation>....</documentation>
  <instance id="SandSack1"/>
  <instance id="SandSack2"/>
  <resources>...</resources>
  <description>
     <name>Sand Sack</name>
     <brief>It is full of sand.</brief>
      <detailed>The sacks seem very heavy. I may be able to carry more than one
   with great effort, although safety regulations do not recommend it.</detailed>
  </description>
  ...
</object>
```

Fig. 17. (a) Markup for the objects; (b) a single object; (c) a collection of objects sharing common descriptive features.

4.6. Cutscenes

Cutscenes are marked up as `cutscene` elements, as formalized in Fig. 16(a). The structure of these elements is very simple. Indeed, the description of the cutscene can contain the fragment of the storyboard describing it, a list of alternative sets of assets used to visualize it, and a list with the next scenes that can be visited once the cutscene has been played. As with scenes, it is possible to mark a cutscene up to identify it as the game's starting point (`start` attribute). In addition, when the cutscene does not have a practicable next scene in the current state of the game, the game finishes. Fig. 16(b) depicts the markup for a simple cutscene.

4.7. Objects

Objects in an <e-Game> document are marked up as `object` elements, as stated in Fig. 17(a). Hence, that <e-Game> discriminates between two different situations:

- There is a single object distinguished (e.g. a toolbox in the case study), which is identified using an `id` attribute (Fig. 17(b)).

(a)
```
<!ELEMENT actions (grab|use-with|give-to)+>
<!ELEMENT grab (documentation?,condition?, effects?)>
<!ELEMENT use-with (documentation?,condition?, effects?)>
<!ATTLIST use-with idTarget IDREF #REQUIRED>
<!ELEMENT give-to (documentation?,condition?, effects?)>
<!ATTLIST give-to idTarget IDREF #REQUIRED>
```

(b)
```
<grab>                    -0-
  <documentation>The hole must have been secured before grabbing
                 the sacks.</documentation>
  <condition>
      <inactive flag="UsedFencesHole"/>
  </condition>
  <effects>
    <trigger-cutscene idTarget="Ambulance"/>
  </effects>
</grab>
```

(c)
```
                          -0-
<use-with idTarget="Toolbox">
  <documentation>It can be used with the toolbox (Dressing room)</documentation>
  <effects>
     <activate flag="UsedCrowbarToolbox"/>
   </effects>
</use-with>
```

(d)
```
                          -0-
<give-to idTarget="Foreman">
   <documentation>It can be given to the foreman, who asks José to go
      to the dressing room and put it in the toolbox.</documentation>
   <effects>
      <speak-char>Put that into the toolbox which is in the dressing
                  room, please</speak-char>
   </effects>
</give-to>
```

Fig. 18. (a) Markup for the actions involving an object; (b) example of a complex *grab* action that triggers a cutscene; (c) example of a *use with* action; (d) example of a *give to* action.

- There is a collection of objects sharing the same features (e.g. in the case study, we can find two sacks of sand, which are identical from a descriptive point of view). In this case, the particular objects that share the description are enumerated using `instance` elements (Fig. 17(c)).

As illustrated in Fig. 17(b) and (c), the textual description of an object is marked up as a `description` element. Authors must provide three kinds of descriptions: a name (`name` element), a brief description (`brief` element), and a detailed one (`detailed` element).

In addition, objects in <e-Game> also include the set of actions that the player is allowed to carry out with each object. Markup for actions is formalized in Fig. 18(a). Actions are enclosed in an `actions` element and can be of the following types:

- The player can pick up the object. This action is marked up as a `grab` element (Fig. 18(b)). Objects without a grab action cannot be picked up.
- A player can combine the object with another one. This action is marked up as a `use-with` element, and the object that can be combined with the current one is referred to using an `idTarget` attribute (Fig. 18(c)).
- The player can also give an item to a character. The corresponding action is marked up as a `give-to` element. The character is referred to with an `idTarget` attribute (Fig. 18(d)).

All these actions may include natural language documentation, as well as conditions and effects. In the case of *grab* actions, the effects are constrained to the activation of flags, triggering of cutscenes, or of having the player speak a line of dialogue. In the case of *use-with* and *give-to* actions, they can also include object consumption and lines spoken by the player or the character affected.

4.8. Characters and the player

Characters are, to some extent, similar to objects, as reflected in Fig. 19(a). It is possible to have either individual characters or collections of common characters. Descriptions of characters are also analogous to those of objects.

(a)
```
<!ELEMENT character (documentation?,instance*,resources*,
                     description,conversations?)>
<!ELEMENT player (documentation?,resources*, description)>
<!ATTLIST character id ID #IMPLIED>
<!ELEMENT conversations (conversation-ref+)>
<!ELEMENT conversation-ref (documentation?,condition?)>
<!ATTLIST conversation-ref idTarget IDREF #REQUIRED>
```

-0-

(b)
```
<character id="Foreman">
  <documentation>The foreman is well into his forties. He always smiles and
   treats his employees fairly, although he usually gets angry at the sight of any
   breach of safety regulations due to a past bad experience that he
   never talks about.</documentation>
  <description>
     <name>Foreman</name>
     <brief>A friendly man with occasional bursts of anger.</brief>
     <detailed>He is the foreman at this construction site. I think I'd better
      not make him angry, cause my work depends on his reports.</detailed>
   </description>
   <conversations>
      <conversation-ref idTarget="greeting">
         <documentation> The first time he speaks, he greets José and welcomes
             him. He advises José on clothing regulations and suggests he
              go to the dressing room.</documentation>
          <condition>
              <inactive flag="SpeakGreeting"/>
          </condition>
       </conversation-ref>
        ...
   </conversations>
</character>
```

Fig. 19. (a) Markup for the characters; (b) an example (the foreman).

Nevertheless, while objects support actions, characters support conversations that can be maintained with the player (`conversations` element) as indicated in Section 3. Each possible conversation is cross-referenced using the `idTarget` attribute of a `conversation-ref` element. In addition, authors are also allowed to specify a condition that must hold before starting a conversation with a character (if not specified, it is assumed to be true). Also notice that Fig. 19(a) includes markup for the player's description (`player` element).

In Fig. 19(b), an example character is depicted. In this example, the reference to a potential conversation is also detailed, while the others are omitted for brevity.

4.9. Conversations

<e-Game> contemplates tree-like conversations between characters and the player, whose structure is characterized in Fig. 20(a). Fig. 20(b) depicts the markup for part of the conversation shown in Fig. 5. According to this markup:

- A conversation always starts with a *dialogue* between the character and the player's avatar. This dialogue is characterized as a talk initiated by the character (`speak-char` element), and continued by either the character (`speak-char` element) or the player's avatar (`speak-player` element).
- The dialogue finishes when a list of options is offered to the (human) player (`response` element), or when the conversation itself is finished (`end-conversation` element, which also encloses the effects achieved by the conversation).
- Each option is in turn characterized by the option itself (marked with an `speak-player` element), followed by another dialogue that could lead to another response (thus leading to the previously mentioned tree-like structure), end the conversation, or go back to the previous set of responses (`go-back` element).

5. The <e-Game> engine

<e-Game> documents and art assets can feed an <e-Game> *engine* in order to execute the documented videogames. The core of this engine is based on the addition of suitable *operational semantics* to the <e-Game>

(a)
```
<!ELEMENT conversation (%dialogue;, %continuation;)>
<!ATTLIST conversation id ID #REQUIRED>
<!ENTITY % dialogue "(speak-char,(speak-char|speak-player)*)">
<!ENTITY % continuation "(response|end-conversation)">
<!ELEMENT response (option)+>
<!ELEMENT option (speak-player,%dialogue;,(%continuation;|go-back))>
<!ELEMENT go-back EMPTY>
<!ELEMENT end-conversation (effects?)>
```

-0-

(b)
```
<conversation id="CompleteSecondTask">
  <speak-char>Well José, did you measure the scaffold?</speak-char>
  <response>
    <option>
      <speak-player>No sir, not yet</speak-player>
      <speak-char>And what are you waiting for, boy?</speak-char>
      <speak-player>At once, sir</speak-player>
      <end-conversation/>
    </option>
    <option>
      <speak-player>Yes sir, it's ready</speak-player>
      <speak-char>And...</speak-char>
      <response>
         <option>
            <speak-player>It's rather tall, sir</speak-player>
            <speak-char>That is not a reasonable measure!</speak-char>
            <speak-char>I need precise data</speak-char>
            <go-back/>
          </option> (...)
```

Fig. 20. (a) Markup for conversations; (b) part of a conversation.

$$\frac{\Phi_o; \; ; \; ...; \; ; \; \Phi_k}{\Psi_o; \; ; \; ..; \; ; \; \Psi_n}$$

Fig. 21. Structure of the inference rules. Each Φ_i in the premise and Ψ_j in the conclusion is an expression in a suitable formal language.

language described in the previous section. This operational semantics are detailed in Section 5.1. In addition, the engine has a highly modular architecture in order to facilitate its adaptation to many different application contexts and to accommodate future evolutions of the <e-Game> language. This architecture is briefly outlined in Section 5.2.

5.1. An operational semantics for the <e-Game> language

Given that <e-Game> is a descriptive markup language for adventure game storyboards, <e-Game> documents can be used for many different purposes (like producing well formatted XHTML documents using an XSL Transformation [4]). Nevertheless, the more relevant use of these documents is to produce running games by automatically processing these documents with the <e-Game> engine. This use relies, in turn, on the addition of well-defined operational semantics for the <e-Game> language. The formal specification of these semantics will be a very useful guide for developers who build and maintain the <e-Game> engine. Therefore, the primary goal of this specification is to provide a strong, unambiguous and implementation-independent description of the dynamic behaviour of the <e-Game> engine, which is a key aspect for a successful language design and implementation process [23]. Besides, regardless of their formal flavour, the specified semantics are based on the usual interactions and system behaviours found in the genre of graphical adventure games, instead of on sophisticated or abstract mathematical concepts. This makes the language easy to use for authors, who will usually have enough intuitive knowledge about these interactions and behaviours.

The description of the <e-Game>'s operational semantics follows the style of the *structural* approach to the specification of the operational semantics of artificial programming languages [16,27,30]. This approach leads to reasonably understandable specifications, which can also be easily prototyped in order to check the adequacy of the subsequent implementation with very little additional effort [5]. According to the approach, the operational semantics of a language are characterized by modelling the behaviour of an abstract machine that executes this language as a *formal calculus* made up of *inference rules*, like those depicted in Fig. 21. The reading of such rules is the usual one: when all the elements in the premise hold, the elements in the conclusion hold. Empty premises can be omitted, and the resulting rules are used to introduce *axioms* into the calculus. Most of the interesting calculi will usually consist

$$\frac{\vdash \langle p,v\rangle \in \rho}{\vdash \rho_p = v}$$

$$\vdash \left(\rho_p := v\right) = \left\{\langle p',v'\rangle \mid \langle p',v'\rangle \in \rho \wedge p' \neq p\right\} \cup \left\{\langle p,v\rangle\right\}$$

Fig. 22. Consulting and updating the values in sets of property–value pairs.

of an infinite number of inference rules. In order to give a finite characterization, a finite number of *rule patterns* can be provided instead by using *syntactic variables*. We will use a *cursive* font to denote syntactic variables in our specification. In addition, this specification will mainly adopt a *small-step* specification style, since we are interested in the rigorous modelling of the basic state transitions of the <e-Game> engine. Nevertheless, we will also give a *big-step* characterization of the overall behaviour of the engine by taking, as usual, the transitive closure of the transition relation in the *small-step* one. In our formalization we will be use the following notations:

- $\vdash \Phi$ for denoting a set-theoretical formula Φ that must hold. In our formalization, we will freely make use of typical first-order logic and set theoretical constructs and operations, and therefore it will be assumed that the <e-Game> semantics will be built upon an appropriate axiomatization for such constructs (see, for instance, [19]). On the contrary, we only define the set-related notations specifically introduced for the <e-Game> semantics. This is the case for the sets of property–value pairs that will be used for several purposes in the semantics, in order to facilitate the modular evolution of the specification without the need to resort to more sophisticated formalisms with built-in modularity facilities, like [26]. In Fig. 22, we provide consulting and updating facilities for managing these sets. With ρ_p, we will denote the value of property p in set ρ. With $\rho_p := v$, we will denote the set that results from substituting the value of p in ρ by v.
- $s_o \rightarrow s_1$ for denoting a basic (small-step) state transition.
- $s_o \rightarrow_+ s_1$ for denoting that the state s_1 can be reached from the state s_o with a sequence of one or more basic state transitions (i.e. for denoting a big-step state transition).

In the following sections, we describe this <e-Game>'s operational semantics. We will start by designing a suitable formal representation for the computation states of a very high-level and abstract intended view of the <e-Game> engine. Then we will formalize <e-Game>'s semantics rules.

5.1.1. Computation states

In Fig. 23, a very high-level view of the <e-Game> engine is informally outlined. According to this view, the engine is made up of a *core* and a *user interface*, which are connected using two streams: *input* and *output*. The user interface collects the *user's inputs* and puts them in the input stream. The core, in turn, encodes the operational behaviour of the engine, and therefore is able to process the inputs to write *presentation commands* in the output stream according to the description in the <e-Game> document taken as input. These commands are in turn interpreted by the user interface in order to produce suitable presentations.

Therefore, the computation states for this engine will include a suitable abstract representation of the e-game document (which will be maintained invariable during the entire execution), the internal game's state maintained by the game's core, the control state of this core, and the state of the input and the output streams. Notice that the user interface will be actually abstracted in terms of the user's inputs and the presentation commands read and written in such streams. Therefore, the computation state will be formally represented by 5-tuples $\langle \theta, G, \sigma, in, out\rangle$ where:

- G is an abstract representation of the game that is being played. This representation is a set of *information items* containing all the data about the <e-Game> document required to execute the game. For the purposes of formalization, these items will be represented as ordered tuples, and they will include tuples of (but not necessarily restricted to) the types described in Fig. 24. Notice that this representation, which is specially tailored to the formalization described in this section, can be readily generated for each <e-Game> document as a domain-specific *infoset* [7] for such a document. For simplicity, we omit the formalization of the translation process. Also, notice that the representation can include additional information that, like the assets associated with the different elements, could be required for the user interface in order to interpret the presentation commands correctly. In these items, conditions are further represented as ordered pairs $\langle f+, f-\rangle$, where $f+$ is the set of flags that must be active, and $f-$ the set of those that must be inactive. Rules in Fig. 25 introduce shortcuts for accessing these

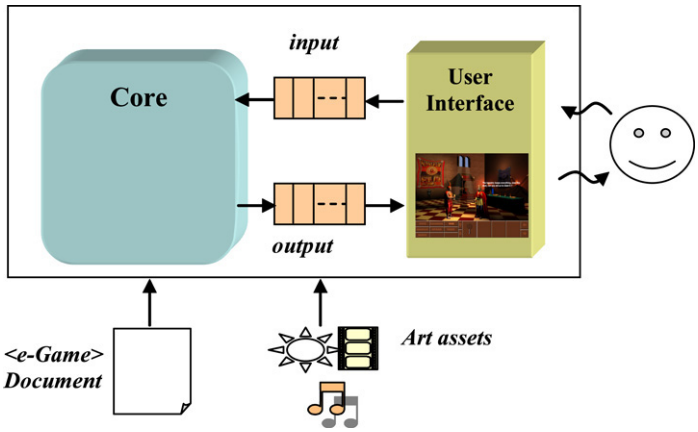


Fig. 23. A very high-level view of the <e-Game> engine.

Information item	Intended meaning	Information item	Intended meaning
<scene,*s*>	*s* is a scene.	<cutscene,*cs*>	*cs* is a cutscene.
<next-scene,*cs*,*ns*,*c*,*es*>	If condition *c* holds, once the cutscene *cs* is finished, it is possible to enter *ns* and get *es* as effects.	<grab,*o*,*c*,*es*>	If condition *c* holds, object *o* can be grabbed. The effect is the achievement of *es*.
<next-scene,*s*,*i*,*ns*,*c*,*es*>	If condition *c* holds, it is possible to go from scene *s* to *ns* by traversing the exit number *i* and to achieve *es* as effects.	<use-with,o_s, o_t ,*c*,*es*>	Object o_s can be combined with object o_t provided that condition *c* holds. Then the effects *es* are achieved.
<object,*s*,o,*c*>	Object *o* is visible in the scene *s* provided that *c* holds.	<give-to,*o*, *ch* ,*c*,*es*>	Object *o* can be given to character *ch* when condition *c* holds. Then effects *es* are achieved.
<character,*s*,*ch*,*c*>	Character *ch* is visible in scene *s* provided that *c* holds.	<conversation,*ch*,*conv*,*c*>	The conversation *conv* can be maintained with character *ch* when condition *c* holds.
<start,*s*>	Scene or cutscene *s* is the starting point.		

Fig. 24. Information items in the abstract representation of the game relevant for the operational semantics.

$$\frac{\vdash c = \langle fs, \_ \rangle}{\vdash \mathrm{F}^{+}(c) = fs}$$

$$\frac{\vdash c = \langle \_, fs \rangle}{\vdash \mathrm{F}^{-}(c) = fs}$$

Fig. 25. Shortcuts for accessing the components of a condition. With _, we will denote an anonymous unique syntactic variable.

two components. In turn, effects are represented as a list of tuples representing the individual effects. In this representation, the first element identifies the effect's type, and the other elements represent the effect's arguments (e.g. $\langle$activate, $f\rangle$ for activating the flag f). Lists themselves will be represented either by $\langle\rangle$ (in case of the empty list) or by $\langle e, l\rangle$ (in case of a list with head e and with rest l). Finally, conversations will be represented as lists of tuples representing the basic conversation steps. Option lists in the conversation will be represented as lists of pairs of the form $\langle m, conv\rangle$, where m is the message to be said by the player, and *conv* is the conversation that follows.

- θ is the control state of the engine's core. This state is used to decide how the execution is to proceed. It is represented as a set of property–value pairs. In Fig. 26, we characterize the types of control states to be used in the semantics. Ctrl-enter(s) indicates that the player is entering the scene or cutscene s, while ctrl-in(s) indicates that

$$\vdash \text{ctrl-enter}(s) = \{\langle \text{ctrl,enter}\rangle, \langle \text{scene},s\rangle\}$$

$$\vdash \text{ctrl-in}(s) = \{\langle \text{ctrl,in}\rangle, \langle \text{scene},s\rangle\}$$

$$\vdash \text{ctrl-app-effects}(es,\theta) = \{\langle \text{ctrl,app-effects}\rangle, \langle \text{effects},es\rangle, \langle \text{next-ctrl},\theta\rangle\}$$

$$\vdash \text{ctrl-use-with}(o,es,\theta) = \text{ctrl-app-effects}(es,\theta) \cup \{\langle \text{obj},o\rangle\}$$

$$\vdash \text{ctrl-give-to}(o,ch,es,\theta) = \text{ctrl-app-effects}(es,\theta) \cup \{\langle \text{obj},o\rangle, \langle \text{char},ch\rangle\}$$

$$\vdash \text{ctrl-talking}(s,ch,conv) = \{\langle \text{ctrl,talking}\rangle, \langle \text{scene},s\rangle, \langle \text{char},ch\rangle, \langle \text{conv},conv\rangle\}$$

$$\vdash \text{ctrl-goto-choosing}(\theta,os) = (\theta_{\text{ctrl}} := \text{choosing})_{\text{options}} := os$$

$$\vdash \text{ctrl-goto-talking}(\theta,conv) = (\theta_{\text{ctrl}} := \text{talking})_{\text{conv}} := conv$$

$$\vdash \text{ctrl-game-over} = \{\langle \text{ctrl,game-over}\rangle\}$$

Fig. 26. Characterization of the control states of the engine's core.

$$\frac{\vdash \theta_{\text{ctrl}} = \text{enter} ;; \vdash \theta_{\text{scene}} = s}{\vdash \text{is-enter}(\theta,s)}$$

$$\frac{\vdash \theta_{\text{ctrl}} = \text{in} ;; \vdash \theta_{\text{scene}} = s}{\vdash \text{is-in}(\theta,s)}$$

$$\frac{\vdash \theta_{\text{ctrl}} = \text{app-effects} ;; \vdash \theta_{\text{effects}} = es}{\vdash \text{is-app-effects}(\theta,es)}$$

$$\frac{\vdash \theta_{\text{ctrl}} = \text{talking} ;; \vdash \theta_{\text{conv}} = conv}{\vdash \text{is-talking}(\theta,conv)}$$

$$\frac{\vdash \theta_{\text{ctrl}} = \text{choosing} ;; \vdash \theta_{\text{options}} = os}{\vdash \text{is-choosing}(\theta,os)}$$

Fig. 27. Shortcuts for discriminating between control states and for accessing some of their properties.

$$\vdash \text{gs-init} = \{\langle \text{flags},\emptyset\rangle, \langle \text{inv},\emptyset\rangle\}$$

Fig. 28. The game's initial state.

he/she is actually in s. Ctrl-app-effects(es, θ') indicates that effects es must be applied, and, if the application is completed, control state θ' must be used in continuation. Ctrl-use-with(o, es, θ') indicates an object as an additional context for the application of such effects, and ctrl-give-to(o, ch, es, θ') indicates an object and a character as such an additional context. Ctrl-talking(s, ch, $conv$) indicates that the conversation $conv$ is being carried out with character ch in scene s. Ctrl-goto-choosing(θ', os) changes such a state to let the player choose an option, while ctrl-goto-talking(θ', $conv$) changes the choosing state to the talking one and sets the conversation associated with the option chosen. Finally, ctrl-game-over is the state associated with the end of the game. In Fig. 27, a set of rules for discriminating between these control states and accessing some of their relevant properties is introduced.

- σ represents the game state. As with the control state, it will be represented as a set of property–value pairs. In the semantics presented in this paper, this state includes two properties: the set of active flags (*flags*) and the set of objects in the inventory (*inv*). The game's initial state is characterized in Fig. 28. Rules in Fig. 29 introduce a notation for testing when a condition c holds in a game state σ' — holds(c, σ'); when an object or a character e is in a scene s of the game G provided the game state σ'—is-in-scene(G, σ', s, e); when an object o is visible in such conditions, either by being in the scene or being in the inventory—is-visible(G, σ', s, o); and when a cutscene cs triggers the end of the game G given the state σ'—is-game-over(cs, σ', G).

$$\frac{\vdash F^{+}(c) \subseteq \sigma_{\text{flags}};; \vdash F^{-}(c) \cap \sigma_{\text{flags}} = \emptyset}{\vdash \text{holds}(c,\sigma)}$$

$$\frac{\vdash \langle \text{object},s,e,c\rangle \in G \vee \langle \text{character},s,e,c\rangle \in G \;;;\; \vdash \text{holds}(c,\sigma)}{\vdash \text{is-in-scene}(G,\sigma,s,\text{e})}$$

$$\frac{\vdash \text{is-in-scene}(G,\sigma,s,o) \vee o \in \sigma_{\text{inv}}}{\vdash \text{is-visible}(G,\sigma,s,o)}$$

$$\frac{\vdash \langle \text{cutscene},cs\rangle \in G \;;;\; \vdash \nexists \text{ns},\text{c},\text{es}(\langle \text{next-scene},cs,\text{ns},\text{c},\text{es}\rangle \in G \wedge \text{holds}(\text{c},\sigma))}{\vdash \text{is-game-over}(cs,\sigma,G)}$$

Fig. 29. Some rules for dealing with the game's state.

User's input	Intended meaning	User's input	Intended meaning
<go,*e*>	Go to the exit *e* in the current scene.	<give-to,*o*,*ch*>	Give object *o* stored in the inventory to character *ch*.
<inspect,*e*,*l*>	Inspect element *e* (object or character) in the current scene with a detail level *l* (*brief* or *detailed*).	<talk-to,*ch*>	Initiate a conversation with character *ch*.
<grab,*o*>	Grab object *o* in the current scene.	<select,*o*>	Continue the current conversation from option *o*.
<use-with,o_s,o_t>	Combine object o_s in the inventory with object o_t, in the current scene.		

Fig. 30. Encoding of the user's inputs.

- *in* is the input stream. This stream will be represented as a list. In this case this list will contain the user's actions, which will be represented as tuples of the types shown in Fig. 30.
- *out* is the output stream. It will contain the presentation's commands represented as tuples, whose intended meaning will be clear from the context of use (e.g. ⟨do-inspect, o, l⟩ will be the presentation command associated with the inspection of object o with a level of detail l). The stream itself will be represented using ⟨⟩ for the empty stream, and pairs of the form ⟨s, e⟩ for the result of appending element e to stream s.

5.1.2. Semantic rules

In Fig. 31, the rules characterizing the state transitions caused by the application of effects are shown:

- Rule *end-apply-effects* deals with an empty list of effects. In this case, the control state indicated as a continuation is established as a new control state.
- The other rules address the application of the different types of effects. The *activate-flag* rule adds the activated flag to the set of active flags in the game's state. The *speak-player1* and *speak-char1* rules write suitable presentation commands in the output to force the player's avatar or the character to speak. The *consume-obj* rule extracts the current object from the inventory (this object will be the value of the *obj* property). Finally, the *trigger-cs* rule causes the indicated cutscene to be entered by setting a suitable control state. Notice that all the rules except this last one imply the application of the rest of the effects. On the contrary, *trigger-cs* interrupts the application of the list of effects (regardless of the fact that the corresponding effect should be the last on such a list), discards the continuation state, and forces a control state to lead to the triggering of the cutscene.

The rules in Fig. 32 formalize the walk through the scenes and the cutscenes:

- Rule *entering* establishes what happens when a scene or cutscene is entered: a presentation command for playing it is written in the output.
- The logic for abandoning a cutscene is mirrored in the rules *leaving-cs* and *game-over*. In *leaving-cs*, a suitable next scene is discovered, whose condition is active and therefore the referred-to destination can be entered. In turn, *game-over* deals with the case where such a next exit is not found. In this case the game terminates.

$$\frac{\vdash \text{is-app-effects}(\theta, \langle\rangle)}{\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \theta_{\text{next-ctrl}}, G, \sigma, in, out\rangle} \textbf{ end-apply-effects}$$

$$\frac{\vdash \text{is-app-effects}(\theta, \langle\langle \text{activate-flag}, f\rangle, es\rangle)}{\left\{\begin{array}{l}\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \theta_{\text{effects}} := es, G, \sigma_{\text{flags}} := \sigma_{\text{flags}} \cup \{f\}, \\ \quad in, \langle out, \langle \text{do-activate-flag}, f\rangle\rangle\rangle\end{array}\right\}} \textbf{ activate-flag}$$

$$\frac{\vdash \text{is-app-effects}(\theta, \langle\langle \text{speak-player}, m\rangle, es\rangle)}{\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \theta_{\text{effects}} := es, G, \sigma, in, \langle out, \langle \text{do-speak-player}, m\rangle\rangle\rangle} \textbf{ speak-player1}$$

$$\frac{\vdash \text{is-app-effects}(\theta, \langle\langle \text{speak-char}, m\rangle, es\rangle)}{\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \theta_{\text{effects}} := es, G, \sigma, in, \langle out, \langle \text{do-speak-char}, \theta_{\text{char}}, m\rangle\rangle\rangle} \textbf{ speak-char1}$$

$$\frac{\vdash \text{is-app-effects}(\theta, \langle \text{consume-object}, es\rangle)}{\left\{\begin{array}{l}\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \theta_{\text{effects}} := es, G, \sigma_{inv} := \sigma_{\text{inv}} - \{\theta_{\text{obj}}\}, \\ \quad in, \langle out, \langle \text{do-consume-object}, \theta_{\text{obj}}\rangle\rangle\rangle\end{array}\right\}} \textbf{ consume-obj}$$

$$\frac{\vdash \text{is-app-effects}(\theta, \langle\langle \text{trigger-cs}, cs\rangle, \_\rangle)}{\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \text{ctrl-enter}(cs), G, \sigma, in, \langle out, \langle \text{do-trigger-cs}, cs\rangle\rangle\rangle} \textbf{ trigger-cs}$$

Fig. 31. Application of the effects.

$$\frac{\vdash \text{is-enter}(\theta, s)}{\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \text{ctrl-in}(s), G, \sigma, in, \langle out, \langle \text{do-enter}, s\rangle\rangle\rangle} \textbf{ entering}$$

$$\frac{\left\{\begin{array}{l}\vdash \text{is-in}(\theta, cs)\ ;;\ \vdash \langle \text{cutscene}, cs\rangle \in G\ ;; \\ \vdash \langle \text{next-scene}, cs, ns, c, es\rangle \in G\ ;;\ \vdash \text{holds}(c, \sigma)\end{array}\right\}}{\left\{\begin{array}{l}\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \text{ctrl-app-effects}(es, \text{ctrl-enter}(ns)), \\ \quad G, \sigma, in, \langle out, \text{do-leaving}\rangle\rangle\end{array}\right\}} \textbf{ leaving-cs}$$

$$\frac{\vdash \text{is-in}(\theta, cs)\ ;;\ \vdash \text{is-game-over}(cs, \sigma, G)}{\langle \theta, G, \sigma, in, out\rangle \rightarrow \langle \text{ctrl-game-over}, G, \sigma, in, \langle out, \text{do-finish}\rangle\rangle} \textbf{ game-over}$$

$$\frac{\left\{\begin{array}{l}\vdash \text{is-in}(\theta, s)\ ;;\ \vdash \langle \text{scene}, s\rangle \in G\ ;; \\ \vdash \langle \text{next-scene}, s, e, ns, c, es\rangle \in G\ ;;\ \vdash \text{holds}(c, \sigma)\end{array}\right\}}{\left\{\begin{array}{l}\langle \theta, G, \sigma, \langle\langle \text{go}, e\rangle, in\rangle, out\rangle \rightarrow \langle \text{ctrl-app-effects}(es, \text{ctrl-enter}(ns)), \\ \quad G, \sigma, in, \langle out, \langle \text{do-leaving}, e\rangle\rangle\rangle\end{array}\right\}} \textbf{ leaving-s}$$

Fig. 32. Entering and leaving scenes and cutscenes, and finishing the game.

$$\frac{\vdash \text{is-in}(\theta, s)\ ;;\ \vdash \text{is-visible}(G, \sigma, s, e)}{\langle \theta, G, \sigma, \langle\langle \text{inspect}, e, l\rangle, in\rangle, out\rangle \rightarrow \langle \theta, G, \sigma, in, \langle out, \langle \text{do-inspect}, e, l\rangle\rangle\rangle} \textbf{ inspect}$$

Fig. 33. Inspecting objects and characters.

- The logic for abandoning scenes is, in turn, reflected in *leaving-s*, which is almost identical to *leaving-cs* with the exception of the user being the one who chooses the exit where he/she wants to go.

The inspection of objects and characters is formalized in Fig. 33 with the rule *inspect*. Notice that only the visible elements (including the objects in the inventory) can be inspected.

The different actions applicable to objects (grabbing them, combining them with other objects, and donating them to other characters) are formalized in Fig. 34:

$$\frac{\left\{\begin{array}{l}\vdash \text{is-in}(\theta,s)\ ;;\ \vdash \text{is-in-scene}(G,\sigma,s,o)\ ;;\\ \vdash \langle \text{grab},o,c,es\rangle \in G\ ;;\ \vdash \text{holds}(c,\sigma)\end{array}\right\}}{\left\{\begin{array}{l}\langle\theta,G,\sigma,\langle\langle \text{grab},o\rangle,in\rangle,out\rangle \to \langle \text{ctrl-app-effects}(es,\theta),\\ \qquad\qquad G,\sigma_{\text{inv}} := \sigma_{\text{inv}} \cup \{o\},\\ \qquad\qquad in,\langle out,\langle \text{do-grab},o\rangle\rangle\rangle\end{array}\right\}} \textbf{ grabbing}$$

$$\frac{\left\{\begin{array}{l}\vdash \text{is-in}(\theta,s)\ ;;\ \vdash \langle \text{use-with},o_s,o_t,c,es\rangle \in G\ ;;\\ \vdash o_s \in \sigma_{inv}\ ;;\ \vdash \text{is-in-scene}(G,\sigma,s,o_t)\ ;;\ \text{holds}(c,\sigma)\end{array}\right\}}{\left\{\begin{array}{l}\langle\theta,G,\sigma,\langle\langle \text{use-with},o_s,o_t\rangle,in\rangle,out\rangle \to \langle \text{ctrl-use-with}(o_s,es,\theta),G,\sigma,\\ \qquad\qquad in,\langle out,\langle \text{do-comb},o_s,o_t\rangle\rangle\rangle\end{array}\right\}} \textbf{ combining}$$

$$\frac{\left\{\begin{array}{l}\vdash \text{is-in}(\theta,s)\ ;;\ \vdash \langle \text{give-to},o,ch,c,es\rangle \in G\ ;;\\ \vdash o \in \sigma_{inv}\ ;;\ \vdash \text{is-in-scene}(G,\sigma,s,ch)\ ;;\ \text{holds}(c,\sigma)\end{array}\right\}}{\left\{\begin{array}{l}\langle\theta,G,\sigma,\langle\langle \text{give-to},o,ch\rangle,in\rangle,out\rangle \to \langle \text{ctrl-give-to}(o,ch,es,\theta),\\ \qquad\qquad G,\sigma,in,\langle out,\langle \text{do-give-to},o,ch\rangle\rangle\rangle\end{array}\right\}} \textbf{ giving}$$

Fig. 34. Using the objects.

- Grabbing an object is supported by the *grabbing* rule. For an object to be grabbed, it must be in the scene, grabbing it must be permitted, and the user must *want* to grab it. The object is added to the inventory, and the corresponding effects are applied.
- The combination of objects is addressed in the *combining* rule. The source object must be in the inventory, the target object must be in the scene, the combination must be allowed by the game description, it must be feasible in the current state, and the user must trigger such a combination. The result is the application of the effects induced by the action.
- Finally, the donation of an object to a character is contemplated by the *giving* rule. The object donated must be in the inventory, the character must be in the scene, the donation must be contemplated in the game description, and it also must be viable in the current state and desired by the user. As a result, the donation is carried out by executing the corresponding effects.

The characterization of the operational semantics of the conversations with the characters is addressed by the rules in Fig. 35:

- The *init-conv* rule characterizes the beginning of a conversation: the character is in the current scene, is able to maintain a conversation in the current game state, and the user initiates such a conversation. Then the control state is properly established to proceed with the conversation.
- A dialogue that proceeds automatically between the characters and the player's avatar is managed by the *speak-player*2 and the *speak-char*2 rules. These rules reflect the writing of the corresponding presentation commands in the output.
- Interaction with the user in order to let him/her choose an option is addressed by the *choosing*1 and *choosing*2 rules. The first rule deals with the presentation of a list of options during the course of the conversation. Notice that the option list itself is stored in the control state in order to backtrack to it if needed. The second rule deals with the actual selection of an option, and the conversation continues by the branch attached to that option.
- Backtracking to the nearest option list is actually addressed by the *going-back* rule.
- Finally, the *ending-conv* rule deals with the end of the conversation and applies the corresponding effects.

Finally, the big-step rules in Fig. 36 deal with the behaviour of the engine itself. Rule *playing* takes the transitive closure of the state transition relation. In turn, rule *play* models the complete behaviour, starting at an initial state and ending at a final one.

As a final remark, notice that a game can exhibit several sources of non-determinism, as revealed by this formal specification of the semantics (e.g. an exit can be practicable in several ways, a character is able to maintain several conversations, combining two objects or giving one to a character can have several associated effects, etc.). Practical implementation will deal with a non-deterministic situation by randomly choosing one of the possible outcomes.

$$\frac{\left\{\begin{array}{l}\vdash \text{is-in}(\theta,s)\ ;;\ \vdash \text{is-in-scene}(G,\sigma,s,ch)\ ;;\\ \vdash \langle \text{conversation},ch,conv,c\rangle \in G\ ;;\ \vdash \text{holds}(c,\sigma)\end{array}\right\}}{\left\{\begin{array}{l}\langle\theta,G,\sigma,\langle\langle \text{talk-to},ch\rangle,in\rangle,out\rangle \rightarrow \langle \text{ctrl-talking}(s,ch,conv),\\ \qquad\qquad G,\sigma,in,\langle out,\langle \text{do-talk-to},ch\rangle\rangle\rangle\end{array}\right\}} \textbf{ init-conv}$$

$$\frac{\vdash \text{is-talking}(\theta,\langle\langle \text{speak-player},m\rangle,conv\rangle)}{\langle\theta,G,\sigma,in,out\rangle \rightarrow \langle\theta_{\text{conv}} := conv,G,\sigma,in,\langle out,\langle \text{do-speak-player},m\rangle\rangle\rangle} \textbf{ speak-player2}$$

$$\frac{\vdash \text{is-talking}(\theta,\langle\langle \text{speak-char},m\rangle,conv\rangle)}{\langle\theta,G,\sigma,in,out\rangle \rightarrow \langle\theta_{\text{conv}} := conv,G,\sigma,in,\langle out,\langle \text{do-speak-char},\theta_{\text{char}},m\rangle\rangle\rangle} \textbf{ speak-char2}$$

$$\frac{\vdash \text{is-talking}(\theta,\langle\langle \text{options},os\rangle,\langle\rangle\rangle)}{\left\{\begin{array}{l}\langle\theta,G,\sigma,in,out\rangle \rightarrow \langle \text{ctrl-goto-choosing}(\theta,os),\\ \qquad\qquad G,\sigma,in,\langle out,\langle \text{do-choosing},os\rangle\rangle\rangle\end{array}\right\}} \textbf{ choosing1}$$

$$\frac{\vdash \text{is-choosing}(\theta,os)\ ;;\ \vdash \langle o,conv\rangle \in os}{\left\{\begin{array}{l}\langle\theta,G,\sigma,\langle\langle \text{select},o\rangle,in\rangle,out\rangle \rightarrow \langle \text{ctrl-goto-talking}(\theta,conv),\\ \qquad\qquad G,\sigma,in,\langle out,\langle \text{do-choosen},o\rangle\rangle\rangle\end{array}\right\}} \textbf{ choosing2}$$

$$\frac{\vdash \text{is-talking}(\theta,\langle \text{go-back},\langle\rangle\rangle)}{\langle\theta,G,\sigma,in,out\rangle \rightarrow \langle\theta_{\text{ctrl}} := \text{choosing},G,\sigma,in,\langle out,\langle \text{do-going-back},\theta_{\text{options}}\rangle\rangle\rangle} \textbf{ going-back}$$

$$\frac{\vdash \text{is-talking}(\theta,\langle\langle \text{end-conversation},es\rangle,\langle\rangle\rangle)}{\left\{\begin{array}{l}\langle\theta,G,\sigma,in,out\rangle \rightarrow \langle \text{ctrl-app-effects}(es,\text{ctrl-in}(\theta_{\text{scene}})),\\ \qquad\qquad G,\sigma,in,\langle out,\text{do-end-conv}\rangle\rangle\end{array}\right\}} \textbf{ ending-conv}$$

Fig. 35. Talking.

$$\frac{s_o \rightarrow s_1\ ;;\ s_1 \rightarrow_+ s_2}{s_o \rightarrow_+ s_2} \textbf{ playing}$$

$$\frac{\left\{\begin{array}{l}\vdash \langle \text{start},s\rangle \in G\ ;;\ \langle \text{ctrl-enter}(s),G,\text{gs-init},in,\langle\rangle\rangle \rightarrow_+ \langle\theta,G,\sigma,\langle\rangle,out\rangle\ ;;\\ \vdash \theta_{\text{ctrl}} = \text{game-over}\end{array}\right\}}{\langle G,in\rangle \rightarrow_+ \langle\theta,G,\sigma,\langle\rangle,out\rangle} \textbf{ play}$$

Fig. 36. Playing the game.

These situations could be considered as a flaw in a fixed storyboard. However, they should not be considered a design flaw in the <e-Game> language. Although in the current implementation the engine issues a warning whenever these situations are detected, authors may want to innovate and explore this kind of non-deterministic behaviour.

5.2. Implementation details

The architecture of the <e-Game> engine is depicted in Fig. 37. This architecture is a refinement of the high-level view of Fig. 23, and its design has been driven by the operational semantics described above. According to this architecture, the engine includes the following elements:

- A *tree builder*. This artefact is based on a standard DOM parser [2], and it builds a tree representation of the <e-Game> document.
- A *component repository*. This repository contains a set of *game components*, which can be adequately selected and assembled to create the final videogame. There are two kinds of game components: *core rules*, which

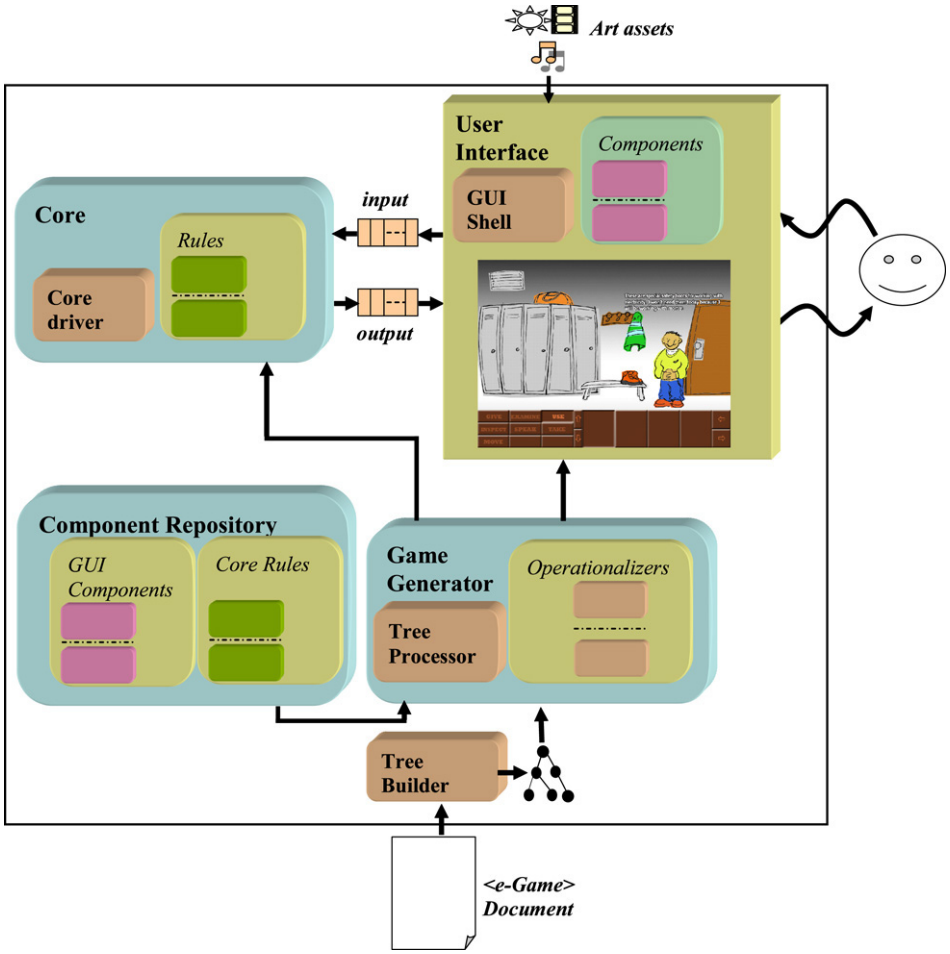


Fig. 37. Architecture of the <e-Game> engine.

roughly correspond to the small-step rules of the <e-Game> operational semantics, and *GUI components*, which implement interaction and presentation services for supporting the final presentation layer of the videogame. These components follow a common component model, which is an evolution of the model described in [37].

- The *core* and *user interface* were presented in the previous subsection. The engine core can be customized with an appropriate set of core rules, and it includes a *core driver* that implements the selection and application strategies for such rules. The behaviour of this driver roughly corresponds with that modelled by the big-step rules of the semantics, enriched with randomized conflict resolution. In turn, the user interface is customized with a suitable collection of GUI components, and its behaviour is controlled by a pre-established *GUI shell*.
- A *game generator*. This artefact processes the document, selects the appropriate game components, and registers them in the core and user interface of the engine. The game generator is architected according to the model for the incremental construction of processors for domain-specific markup languages described in [39]. Therefore, it contains a general-purpose *tree processor* and a set of *operationalizers* that are used to assign a set of semantic attributes and an evaluator to each node of the document tree. In turn, the evaluators will be responsible for computing these values for the semantic attributes associated with their nodes.

This architecture is modular enough to accommodate evolutions in the <e-Game> language, as we realised at earlier design stages of this language. Indeed, these evolutions are confronted by extending the game generator with new operationalizers, with the modification and/or adaptation of existing ones, with the addition of new game components to the component repository, and with the extension and/or replacement of existing ones. In addition, the predefined components are simple enough to be extended, modified, or even replaced if required.

6. Qualitative evaluation of the approach's usability

In order to assess the usability of the documental approach and <e-Game>, we have collected feedback from two different application scenarios:

- The first evaluation consisted of the implementation of the case study about safety regulations discussed above in the present paper. Three informal volunteer writers independently followed the steps suggested and reported the difficulties found at each step. An artist provided a single set of assets to be used by the three authors. The writers had been previously exposed to the <e-Game> syntax and had some working experience using XML technologies. They had also played several graphical adventure games and were familiar with the genre. On the other hand, they had not been exposed to the operational semantics of the language or to any details of the engine. This is relatively close to the average expected user of <e-Game>, although previous XML experience should not be a requisite.
- The second experience describes a more challenging scenario, carried out in collaboration with the Spanish National Center of Information and Educative Communication (CNICE, an office of the Spanish Ministry of Science and Education). CNICE contains Spain's largest repository of educational computer assisted material written in Spanish, including interactive videogames to support K-12 education. The experience consisted in reusing the instructional design and the art assets of the videogames corresponding to a *History of Music* course provided by the CNICE. Those games were not adventure games strictly speaking, which added the challenge of having to write an entirely new story adapted to the needs of the genre. Thus, a repurposed and redesigned version of those games was made using the <e-Game> project, with promising results.

The reports presented by the writers and the artists during these experiences highlighted some caveats of the process and provide interesting ideas for future development:

- The storyboard authoring guidelines were accepted as quite a natural way to write an adventure game, although keeping the descriptions of the objects, characters and conversations apart felt a bit strange at first. When reassured that the size of the definition of a scene would be manageable if the writers included the full definitions of all the characters, including complete conversations, the methodology was accepted as reasonable.
- In the repurposing experience, several authors reported that fixed tree-like conversations were excessively limiting when compared to current adventure game standards. The complex conversation system of *Star Wars: Knights of the Old Republic*[21] was suggested as an ideal.
- The condition system, which is one the most delicate design choices in <e-Game>, did not cause special problems. The results suggest that its use is intuitive while being powerful enough to cover most of the usual situations in typical graphical adventures. We confirmed with authors that the use of conjunctive normal forms for expressing conditions was more natural in this context than the pattern-matching intuition behind disjunctive normal forms.
- Authors who attempted to mark up long conversations directly using XML syntax reported the experience as unmanageable. On the other hand, marking directly on top of the simplified structure of the storyboard in a systematic way proved to be an effective method to mark up relatively long conversations. Given their smaller size, the short conversations from the case study did not cause similar problems and proved to be manageable.
- The authors complained about the lack of an easy-to-use mechanism to adjust the coordinates for the positioning of objects, characters and exits. Currently, the mechanism is purely manual and trial and error approaches are enormously time consuming, thus proving the necessity for artists to collaborate during this stage.
- For the artists, cutscenes done manually were challenging both in effort and in technological knowledge (the used setting of the engine was able to reproduce only MPEG videos, and authoring and coding MPEG assets is not an easy task without a technical background).

However, the main result of our experiences was the realization that writers could easily learn and dominate the operational and presentational aspects of the language, to the point of being able to maintain <e-Game> documents on their own. When they reach the adequate level of proficiency, they can proceed with little support from the other participants.

[21] http://www.lucasarts.com/products/swkotor/: It must be noted that Knights of the Old Republic is not an adventure game, but a Role-Playing Game in which the player character has specific attributes. Its conversation system includes options and outcomes dependant on the characteristics of the player character.

7. Conclusions and future work

In this paper, we have presented a documental approach to the development of graphical adventure videogames that provides a rational collaboration framework between writers, artists and computer technicians. This approach has been implemented in the <e-Game> project, by defining the <e-Game> language and building the <e-Game> engine.

The <e-Game> language has been designed to mark up storyboards for a very specific videogame genre. On the one hand, this narrowing of the genre increases the simplicity and the usability of the language. On the other hand, it sacrifices flexibility, and it is not possible to develop videogames outside this genre using <e-Game>. Nevertheless, as indicated in [25], it would be possible to provide languages and engines to support other types of games, as long as they can be meaningfully described using marked up documents. Hence the documental approach promotes the definition of domain-specific languages for each domain and, the more precise the domain, the simpler the authoring process can be.

We have also detected some issues in the approach during our experience with <e-Game>. Our work in the near future will be oriented to tackle these issues. On the one hand, we have realized that there is an extensive use of XML required (usually an error-prone task), and working with coordinates is not comfortable for writers. Such conflictive tasks may benefit from a different authoring approach in which the author is provided with a GUI, as with several of the tools presented in Section 2. On the other hand, we have noted that one of the most controversial design decisions is that <e-Game> was too limiting with regard to the expressivity of its conversation system. This is perhaps the most delicate point when trying to find a balance between simplicity and power. The insights provided by the authors suggest that the simple tree-like structures marked up with the present syntax of the <e-Game> language is near the frontier of some authors' expertise, while more experienced authors demand more expressive power, such as conditioned answers (using the condition system) or an enhancement of the tree structure (a graph structure was suggested). To address this point, we will explore the implications of different dialects of the <e-Game> language to accommodate different levels of expertise. A similar approach has already been successfully applied in the context of some XML-based languages. One of the most notorious examples of this is the definition in Levels (A, B and C) of the IMS Learning Design specification [18]. IMS Learning Design authors may initially sacrifice part of the power of the specification for the sake of a simpler use. Later on, if an author feels comfortable managing the basic syntax and is limited by it, he/she may start using the next level. In <e-Game>, we will explore different types of conversations. In particular, we will support conversations structured as graphs, although it must be noted that defining graphs in an XML document is a reference-intensive process and requires a certain level of expertise.

As of now, we have mainly applied this model in the educational domain. As described in [21], we are working on the integration of <e-Game> with different e-learning platforms, including our <e-Aula> experimental Leaning Management System [38,41]. Nevertheless, we also would like to apply <e-Game> to alternative environments besides the educational domain of our case studies. Of course, <e-Game> is not expected to have a significant impact on the mainstream videogame business, where high-tech commercial games with huge development costs are the stars of this medium, and the current market demand is not likely to change anytime soon. However, there are alternative markets in which <e-Game> can be a very useful tool. The most obvious example is, of course, Interactive Fiction, but there are other fields that may benefit from this approach like casual gaming, advertising or the diffusion of ideas.

Finally, taking advantage of the formal grounding of the <e-Game> language, we are also working on the application of several validation tasks (e.g. reachability analysis, shortest path to end the game, etc.) to the marked storyboards.

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